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Open versus Closed Kinetic Chain Exercise in the Lower Extremity

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OPEN VERSUS CLOSED KINETIC CHAIN EXERCISE IN THE LOWER EXTREMITY

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ABSTRACT

This study is a literature review comparing and contrasting the advantages of closed kinetic chain exercise over open kinetic chain exercise. It is the purpose of this study to show that open kinetic chain exercise may not be the safest or the most functional way to rehabilitate the lower extremity. It is also the purpose to show the specific advantages of using closed kinetic chain exercise over open kinetic chain exercise to protect the integrity of the ACL deficient or reconstructed knee by decreasing anterior shear forces, increasing joint compression, increasing joint proprioception, increasing muscular joint compression, and increasing the functional aspect of the patients rehab.

The current literature suggests that closed kinetic chain activities may be a better choice for rehabilitation over open kinetic chain activities. Research shows that there is scientific evidence that closed kinetic chain exercises are safer and more functional than open kinetic chain exercise due to the fact that closed kinetic chain exercises decrease anterior shear forces, increase muscular co-contraction, increase tibiofemoral joint compression, increase joint proprioception, and are a more functional way to rehabilitate an injury.

CHAPTER 1

Introduction

In recent years, open kinetic chain exercises have been the rehabilitation treatment of choice for the lower extremity following injury. Isokinetics have become common place in muscle strengthening programs, with special emphasis placed on knee extension and the quadriceps muscle.[1] Isokinetic exercise has been used as a method for analyzing force-velocity or power-velocity relationships and as a training and testing device for healthy athletes.[1] It is also used for different clinical purposes such as evaluating rehabilitation or function of joints.[1]

The original isokinetic machine was a speed-controlled laboratory research device developed by Peter Karpovich and Wayne Doss in the late 1950's.[2] Mohan Singh[2] also utilized isokinetics for research purposes at Springfield College in Springfield, Mass. In the late 1960's, Perrine[3] utilized the concept of isokinetics for the purpose of exercise and rehabilitation training. Perrine[3] defines isokinetics as dynamic, pre-set, fixed speed exercise, with accommodating resistance that occurs throughout the entire range of motion.

The current literature suggests that closed kinetic chain exercises may be the better choice for rehabilitation.[4-10]

A review of the literature shows that there is scientific research to support the claims that closed-kinetic chain exercises do have certain advantages over open kinetic chain exercises. Although the concept of closed kinetic chain exercises can be dated back to 1955 when Arthur Steindler defined the terms open and closed kinetic chain in his text book "Kinesiology of the Human Body", there are relatively few articles published comparing the advantages of using closed kinetic chain exercises over open kinetic chain exercises.

Injury to the anterior cruciate ligament (ACL) is one of the most common injuries seen in orthopedics and sports medicine. There seems to be some controversy on how to treat these ACL reconstructed and ACL deficient patients. Rehabilitating these patients can be very challenging to the physical therapist or athletic trainer due to the loss of joint stability, atrophy of the lower extremity muscles with secondary strength loss, a decrease in proprioception of the lower extremity, and the integrity of the ACL itself.

Exercise programs to rehabilitate these patients are designed to maintain and improve knee stability by strengthening the muscles around the joint to compensate for any structural deficiencies and to limit further degeneration of the injured or repaired ACL. Strengthening is also needed to protect the secondary passive restraints of the joint (joint capsule, collateral ligaments) to prevent degeneration or further injury of the joint.[10] Some muscle strengthening exercises cause anterior tibial displacement, which stress the passive restraints of the knee.[10] These stresses to the damaged or repaired ACL may cause stretching and loosening of the ACL graft.[9] Research shows that the ACL graft strength is somewhat compromised at six months, and thus it is emphasized that there is a need for normal proprioceptive and functional patterns in musculature and coordination before exposure to potentially dangerous joint loads.[11] It is important for the physical therapist or athletic trainer doing the patients rehabilitation to have a thorough understanding of the function and anatomy of the ACL, and an understanding of the stresses that certain exercises place on the damaged or repaired ACL. Therapists should know what points in the range of motion of the ACL that these stresses are the most and where the stress is the least.

This review of the literature will compare and contrast closed kinetic chain exercises with open kinetic chain exercises. Open kinetic chain activities have been used routinely to rehabilitate the ACL reconstructed or ACL deficient patient.

It is the purpose of this study to show that open kinetic chain exercise may not be the safest or the most functional way to rehabilitate the lower extremity. It is also the purpose to show the specific advantages of using closed kinetic chain exercise over open kinetic chain exercise to protect the integrity of the anterior cruciate deficient or reconstructed knee by decreasing anterior shear forces, increasing joint compression, increasing joint proprioception, increasing muscular joint compression, and increasing the functional aspect of the patients rehabilitation.

CHAPTER 2

Definitions

There are several definitions of an open and closed kinetic chain exercises found in the literature. Nordin[12] defines kinetics as involving both static and dynamic analysis of the forces and moments acting on a joint. Kinetic analysis allows one to determine the magnitude of the moments and forces on a joint produced by body weight, muscle action, soft tissue resistance, and externally applied loads in any situation, either static or dynamic, and to identify those situations that produce excessively high moments or forces.[12]

Steindler[8] defined the kinetic chain terminology from the closed kinematic and link concepts set forth by Reuleaux for mechanical engineering purposes. The link concept defines a closed kinematic chain as "rigid overlapping segments that are connected in series by pin joints. Both ends are connected to an immoveable framework, thus preventing translation of either the proximal or distal joint center. This creates a system where movement at one joint produces movement at all other joints in a predictable manner."[8] Steindler stated that although a closed kinematic chain never occurs in the extremities, two types of kinetic chain exist under different limb loading conditions. He observed that when the foot or hand meet considerable resistance, muscle recruitment and joint motion differ from that seen when the foot or hand is completely free to move.[8] From this observation Steindler separated the conditions and described an open kinetic chain as existing when the peripheral joint of the extremity can move freely, such as when waving the hand or moving the foot forward in the swing phase of gait. He described a closed kinetic chain as existing whenever the foot or hand meet resistance, such as in the chin-up or rising from a squat.[8] He also pointed out that a true closed kinetic chain can only exist during isometric exercise, since by definition neither the proximal nor distal segment can move in a closed system.[8]

Closed kinetic chain was described in an article by Galik[5] as a "functional activity", "a whole body concept", or "real life work". Galik[5] quoted a definition of kinetic chain from Steindler saying that the "Kinetic chain is a combination of several successively arranged joints constituting a motor complex."

Gray[13] uses terms like "chain reaction", "integrated isolation", which entails viewing the uninjured site both in isolation and as part of an integrated system, and "eccentrically concentric", which describes muscles within the kinetic chain acting eccentrically at one joint and concentrically at another joint simultaneously. Gray[13] defines open kinetic chain as a combination of several joints united successfully where the end segment is free, as when the limb is in swing phase. Closed kinetic chain is defined as a combination of several joints united successfully where the end segment is not free, as when the limb is in support phase.[13] Stone[9] stated that closed kinetic chain exercises permitted natural lower extremity function with enhanced joint stability through weight-bearing and muscular co-contractions.

Kreighbaum and Barthels[14] define an open kinetic chain by saying, "In performing throwing , kicking, striking, and some pushing skills, the dominant extremity functions as a system of segmental links. It is an open system because the last most distal segment is not fixed but is free to move in space."[14] Closed kinetic chain was not clearly defined but states that "In contrast to the throwing model (open kinetic chain), the jumping model (closed kinetic chain), shows the most massive segment, the trunk, located at the open end of the kinetic chain, and the least massive segment, the foot located at the fixed end."[14]

The concept or principle that goes along with these definitions is described as the "Sequencing segmental rotations: The kinetic link principle". This principle states that "the sequence of segmental rotations used for throwing, kicking, or striking patterns may be compared to the motion of a whip, a fly fishing rod, or the lashing action of a fish’s tail. If segmental rotations are free to occur at each of the distal joints, the body's system of links behaves in a manner similar to a flexible chain of links, with the earth and base segment acting like the handle of a bullwhip. The general pattern of movements is one in which the initial rotation occurs in the base segment, which is the most stable part of the system, and is followed by the forward rotation of the next distal segment. Each segment comes forward as the movements of its proximal segment reaches its greatest angular velocity. The sequencing procedure continues to occur from proximal to distal, one segment's movement overlapping the other until the most distal segment comes forward. In a system of freely rotating segments, as the proximal link angularly accelerates in one direction, the next distal link in the kinetic chain lags back in the opposite direction. The lagging back of the distal segments persists until one or more of the following occurs: 1) the acceleration of the proximal segment decreases or ceases, 2) the elastic or structural limit of a joints range of motion is reached or, 3) the stretch reflex is activated. If the stretch reflex is evoked, elastic recoil occurs, or voluntary intersegmental muscular torques are activated, the lagging segments forward rotation will be initiated."[14]

These definitions have been adopted to describe various strengthening exercises for the lower extremity that are used to rehabilitate the knee.[7] During closed kinetic chain exercises, the foot is fixed and motion at the knee joint is accompanied by motion at the hip and ankle joints in a predictable manner. Examples of this exercise would be the leg press and the squat, which strengthen the quadriceps and hamstrings simultaneously.[7] With open kinetic chain exercises the foot is mobile, and motion at the knee joint occurs independent of motion at the hip and ankle joints. Some examples of these exercises, are leg curls and leg extension exercises, which strengthen the hamstrings and quadriceps respectively.[7]

It is evident that there are several definitions of open and closed kinetic chain exercise in the literature. Palmitiers[8] states that there is a difference in ACL strain during the two types of exercise, but using the open and closed chain terminology to make the distinction is inaccurate. He argues that neither exercise is a closed kinetic chain exercise since either the proximal or distal segment moves in each situation. He also states that you could argue that they are both closed kinetic chains, since the peripheral limb meets resistance in each situation.[8] An important point is that in order to apply accurate terms to these two exercise situations, you need an understanding of how the lower extremity kinetics are altered during weight bearing and non-weight bearing exercise.[8] That is, it is important to understand what kind of stresses the exercises you choose are having on the limb or joint, what kind of stresses the limb or joint can handle, and in which part of the range of motion is the joint most vulnerable? Because of the relative position of the body during activity, closed kinetic chain exercises allow more functional patterns of movement with regard to athletics, and provide for multiplanar isometric, concentric, and eccentric contraction.[15]

CHAPTER 3

Anatomy

The ACL was first described by Galen in 170 A.D.[16] From that time to the present there has been controversy regarding the treatment of the ACL rupture.[16] The first reported surgical procedure to repair chronic knee instability was performed in Leeds, England in 1885.[17] The ACL is the most frequently injured ligament in the body.[16] A study done by Johnson[16] found 1.2% of college freshman ACL deficient in routine entrance exams.

The ACL is an intra-articular, extrasynovial structure which originates from the area anterior and lateral to the anterior tibial spine and inserts into the posteromedial aspect of the lateral femoral condyle.[17] A slip from this ligament also attaches to the anterior horn of the lateral meniscus.[17] The ACL is composed of three distinct fiber bundles, anteromedial, intermediate, and posterolateral, and are oriented to resist stresses from multiple directions.[17] When the knee is fully extended the posterolateral and intermediate bundles become taut and help oppose anterior tibial displacement. The anteromedial fibers remain relatively lax in extension.[17] During flexion, the ACL winds around itself and the fibers from the intermediate and posterolateral bundles become loose while the anterior medial bundle remains taut.[17]

Biomechanical studies of the knee joint show that the knee motion consists of a combination of rolling and sliding motions, with the relative position of the articulating surfaces being controlled by the cruciate ligaments.[16] The ACL is an important structure within the knee joint providing 86% of the total stabilizing force against anterior displacement of the tibia.[1,17] Anterior instability of the knee results when a tear of the ACL is present.[18] The ACL serves as the primary restraint to anterior displacement of the tibia on the femur.[16,18,19] Along with the PCL it governs the biomechanical course of the knee by virtue of its strategic location close to the joints central pivot and its special geometry.[18,20] Knowledge of the anatomy and function of the ACL is crucial in designing a rehabilitation program for the knee.

A cadaver study by Kennedy[21] in 1974 showed that there is little individual variation in the length of the ACL. The lengths ranged from 3.7 to 4.1 cm with the average being 3.9 cm. The study showed that the ACL is taut in full knee extension and in 5 and 20 degrees of flexion, and is most relaxed between 40 and 50 degrees of flexion, and then becomes increasingly taut as you increase flexion from 70 to 90 degrees.[21] Grood found anterior subluxation of the tibia and subsequent loading of the ACL begins in the range of 30 to 40 degrees of quadriceps initiated knee flexion.[22]

Jurist and Otis[16] demonstrated that anterior subluxation in the ACL deficient knee increases as the knee is extended from 90-30 degrees.[16] External tibial loading has been shown to greatly influence the degree of subluxation seen with proximally placed, posteriorly directed force counter acting the anterior pull of the quadriceps mechanism.[16]

During extension of the knee joint, the quadriceps force acts in both a superior and anterior direction in counteracting the weight of the lower limb. The superior force component is normally opposed by the vertical joint reaction force between the femur and tibia and the anterior force by the ACL, which prevents tibial subluxation. When the ACL is absent or incompetent, the anteriorally directed component of the quadriceps force is unopposed and so it causes anterior translation of the proximal tibia until sufficient resistance is developed by stretching the collateral ligaments and adjacent soft tissue structure.[16]

In an open kinetic chain knee extension exercise, the relatively flat tibial plateau surfaces move on the convex femoral condyles. Due to the geometric configuration of the knee, the tibia will glide and roll anteriorly during the knee extension exercise.[23] In addition, due to the anterior attachment of the quadriceps on the tibia, anterior tibial glide is accentuated by a forceful quadriceps contraction.[23]

According to Gray, there are fifteen muscles involved in closed kinetic chain activity of the lower extremity.[13,15]

The primary function of these muscles is to control multiplanar acceleration and deceleration of the lower extremity.[13]

The gluteus maximus is a large and influential muscle of lower extremity function that combines with the iliotibial band and inserts onto the proximal lateral tibia.[15] The gluteus maximus contracts along with the iliotibial band and decelerates internal rotation of the lower leg into external rotation at heel strike.[4,13]

The hamstring muscle group is comprised of the semimembranous and the semitendinous medially, and the biceps femoris laterally. Together these muscles are responsible for hip flexion deceleration and hip extension acceleration. The semimembranous is a medial knee stabilizer and helps prevent valgus collapse. An additional job of the hamstrings is to regulate the loads placed on the knee during extension when the ACL is overloaded.[4,24]

The small, but highly innervated popliteus muscle plays an important role in the rotary stability of the knee.[4] The popliteus muscle pulls the lateral meniscus posteriorly away from the rapidly receding lateral femoral condyle.[4,13]

The gastrocnemius decelerates internal rotation of the femur. Subsequently, tibial rotation is decelerated by the soleus and posterior tibialis muscles, thus decreasing torque at the knee joint.[4]

The posterior tibialis muscle decelerates the tibia at late midstance, just prior to propulsion, thus causing closed chain leg extension.[4,13] The posterior tibialis also decelerates the subtalar joint pronation by eccentrically controlling subtalar joint excursion and lower leg internal rotation.

The quadriceps femoris muscle group is comprised of the rectus femoris, vastus medialis, vastus medialis longus, vastus lateralis, and vastus intermedius.[4] The primary duty of the quadriceps femoris group is to control deceleration of knee flexion at heel strike. The quadriceps work with the posterior tibialis to decelerate the knee and subtalar joint pronation, in the sagittal and frontal planes, respectively.[4,13] Open kinetic chain exercise does not produce or duplicate these pronation forces that occur in closed kinetic chain exercise.[4] Open kinetic chain knee extension and flexion exercise results in minimal co-contraction about the knee joint, causing increased shear forces, lack of hip movement, and isometric stabilizing contraction of the gluteus maximus and tibialis anterior.[4]

CHAPTER 4

Shear Forces

Lutz[7] found that biomechanical, cadaveric, and clinical analysis have demonstrated that traditionally prescribed open kinetic chain extension exercises produce shear forces that load the ACL, especially in the final 30 degrees of extension. The resulting strain on the ligament possibly endangering the ligament or graft as it heals.[7] Open kinetic chain flexion exercises produce shear forces that load the posterior cruciate ligament. Lutz[7] summerizes this by saying that for these reasons, current rehabilitation programs for the anterior cruciate ligament should avoid full range open kinetic chain extension exercises, and open kinetic chain flexion and extension are emphasized to strengthen the hamstrings.

Maltry[16] studied the effects of ACL deficiency on anterior tibial translation during extension of the knee joint at 10, 25, 40, and 60 degrees. He found that in every specimen anterior translation increased with the loss of the ACL and tibial translation was the greatest at 25 degrees of flexion. There was an average displacement of 3.3 mm of anterior displacement. Anterior translation decreased slightly from 25-10 degrees. Subluxation was not significant at flexion angles greater than 60 degrees regardless of ACL deficiency. He also examined the effect of external restraining force on tibial subluxation in ACL deficient knee. He used 0 Newtons, 45 Newtons (10lbs), 90 Newtons (20lbs), 135 Newtons (30lbs), and 225 Newtons (50lbs), applied at the tibial tuberosity. He concluded that tibial displacement increased with knee extension beginning at 60 degrees and reached a maximum at 25 degrees then decreases toward full extension. Also, if ACL repairs and/or secondary soft tissue structures are to be protected from anteriorly directed forces tibial restraint must be employed.[16] Stretching of the secondary restraints can lead to further anterior laxity and more biomechanically complex rotatory instabilities.[25]

John-Yack[10] did a comparison study of closed and open kinetic chain exercises in the anterior cruciate ligament deficient knee. The purpose of his study was to quantify the amount of anterior tibial displacement occuring in ACL deficient knees during the closed kinetic chain exercise the parallel squat, and the open kinetic chain exercise the seated knee extension.

The results showed the averaged anterior tibial displacement during the parallel squat exercise were significantly less than during the knee extension exercise from 66 to 10 degrees of knee extension for the ACL deficient knee. The mean anterior tibial displacement during the Lachman evaluation was significantly less than during the knee extension exercise and significantly more than during the parallel squat exercise. In the normal knees there were no differences in anterior tibial displacement between the Lachman evaluation and the knee extension exercise or the paralle squat exercise.[10]

Closed kinetic chain exercises have been advocated in recent years, primarily because these exercises result in less anterior/posterior shear force at the knee joint when compared with traditionally used open kinetic chain exercises.[6] Anterior/posterior shear forces result from increased quadriceps femoris muscle tension, which produces a potentially dangerous situation in which too much force can be directed through an injured or reconstructed ACL.[6]

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John-Yack[10] concluded that open kinetic chain exercise caused greater anterior tibial displacement than the closed kinetic chain exercise in the ACL deficient knee. These results support Hennings findings that nonweightbearing exercises produced more ACL strain than weightbearing exercises.[26] John-Yack[10] also concluded that knee extension exercise should not be used at any flexion angle less than 64 degrees if the immediate goal of the exercise program is to minimize stress to the ACL·

A recent cadaver study on ACL strain as a consequence of simulated quad contractions has shown significant increases in strain between 0 and 40 degrees of flexion.[27] Howe et al. found significant increases during isometric quadriceps contractions at 30 degrees of flexion compared with 90 degrees in vivo and concluded that this may be detrimental to ACL reconstructions.[27] Consequently numerous authors have recommended that typical knee extension exercises be avoided.[1,27,28] As an alternative closed kinetic chain exercises are emphasized in rehabilitation programs to decrease presumed anterior shear force.[27] When designing a rehab program you need to take into consideration the potential problems associated with anterior/posterior shear on the reconstructed or ACL deficient knee.[6]

Many researchers describe anterior/posterior shear forces resulting from increased muscle tension of the quadriceps muscle, which produce imbalanced muscle forces on the knee, and they warn against using open kinetic exercises after ACL reconstruction.[1,6,24,29] Despite this warning testing protocols that use isokinetic systems are commonly performed even if there is controversy as to their safety.[27]

A research study done by Graham[6] found that closed kinetic chain exercises reduce anterior/posterior shear forces that occur when the extremity is loaded by body weight. Inherent joint stability is provided by the bodies weight and allows for more strenuous strengthening workouts without the degree of shearing forces that occur with open kinetic chain exercises.[6]

Several articles reported a relationship between anterior shear forces and knee joint angle.[1,6,30,31] Lutz[7] compared shear forces at the tibiofemoral joint at 30, 60, and 90 degrees of knee flexion. The closed kinetic chain exercise produced significantly less posterior shear force than did the open kinetic chain extension at all of the knee angles tested. The closed kinetic chain exercise also produced significantly less anterior shear force than did the open kinetic chain flexion exercise at all angles of knee flexion except 30 degrees. Analysis of tibiofemoral compression forces revealed that the closed kinetic chain exercise produced significantly greater compression forces at only 30 degrees of knee flexion.[7]

Although there seems to be support for closed kinetic chain exercises over open kinetic chain exercises, an article by Howe states that there are questions regarding the clinical relevance of anterior tibial displacement during knee extension exercises as there are still unanswered questions because of research design, interpretation, and technical difficulties.[27] Shelbourne[28] states there is a theoretical risk in knee isokinetic testing and isokinetic exercise protocols.

Cybex (Cybex, Lumex Inc., Ronkonkoma, NY) testing has been performed as early as 5 to 6 weeks after surgery with no apparent effects on joint laxity.[27,28] Isokinetic training begun in the 14th postoperative week had no effect on stability, joint motion, or knee function score.[27] Howell found that instrumented laxity testing produced more anterior tibial translation than maximal isometric quadriceps contraction at various knee flexion angles.[7] A study done by Maitland[27] provided evidence that Cybex testing with the standard testing apparatus between 6 and 10 months after patellar tendon autographs did not cause a demonstrable increase in anterior tibial displacement. He found no clinical studies that showed altered passive kinematics of the knee joint in reconstructed knees as a consequence of Cybex testing.[27] He goes on to say however, "that these results may not be reliably extrapolated to more generalized populations of ACL reconstruction patients, as this was not a randomly selected population."[27] Anterior shear forces in the normal tibiofemoral joint during Cybex testing have been estimated to be from about 3 33% to 100% of the body weight.[1,27,30] Thirty three percent of the body weight is comparable to walking.[30] Maitland suggests that isokinetic testing is a reasonable approach to quantifying rehabilitation outcomes in patients six months or more after they have undergone ACL reconstruction using patella tendon autografts.[27]

It is very important to know the shear forces exerted on the knee joint during activities of daily living in order to design a rehabilitation program after ACL reconstruction.[32] There have been numerous studies on shear forces, but none in weight bearing.[31]

CHAPTER 5

Tibiofemoral Joint Forces

Lutz[7] compared tibiofemoral joint forces during open and closed kinetic chain exercises. He found that one of the most common complications after reconstruction of the ACL was patellofemoral pain syndrome. He also states that this pain is exacerbated by open kinetic chain exercises done with the knee flexed to more than 30 degrees, thus training in the 60 to 90 degree range of knee motion is inappropriate.[7] Patellofemoral pain could be prevented by strengthening the quadriceps in the 0-30 degree range of knee motion, but this is the range where maximum stress is placed on the ACL. This has been described as the "paradox" of exercise.[7] Results of Lutz's study showed that during the open kinetic chain extension exercise, maximum posterior shear forces (the resisting forces to the ACL) of 285±120 Newtons occurred at 30 degrees of knee flexion, and posterior shear forces of 160±53 Newtons were observed at 60 degrees of knee flexion. During open kinetic chain flexion exercises, maximum anterior shear forces (the resisting forces to the ACL) of 1780±699 Newtons occurred at 90 degrees of knee flexion. During closed kinetic chain exercises, anterior shear forces were observed at 30, 60, and 90 degrees of knee flexion.

Tibiofemoral compression forces during the open kinetic chain extension exercise, the maximum compression forces of 3765±716 Newtons occurred at 90 degrees of knee flexion. The maximum compression forces (3453±1313N) observed during the closed kinetic chain exercise occurred at 30 degrees of knee flexion. During open kinetic chain extension exercises, compression forces increased with increases in the degree of knee flexion. In contrast, during closed kinetic chain exercise, the compression force decreased with an increasing angles of knee flexion. Open kinetic chain flexion exercises produced the least compression forces of the three exercises.[7]

Lutz[7] concluded that isometric closed kinetic chain exercise produced significantly less tibiofemoral shear force with comparable muscular activity when compared with isometric open kinetic chain exercise. This reduction in shear forces was a result of the more axial orientation of the applied force and the phenomenon of muscular co-contraction. Lutz[7] states that these results provide the necessary scientific rationale for the use of closed rather than open kinetic chain exercise as a means of rehabilitation after an injury to or reconstruction of the ACL.

CHAPTER 6

Limb Torque

The role of limb torque on the lower extremity is another important factor to consider when choosing a rehabilitation program. Segmental torque of the lower extremity is transmitted through the distal extremity to the subtalar joint. The subtalar joint plays an important role in closed kinetic chain by converting torque of the lower leg and also by attenuating transverse plane rotation.[4] Because the conversion of limb torque of the lower extremity occurs at the subtalar joint, closed kinetic chain rehabilitation appears to be clinically safer than open kinetic chain rehabilitation due to reduced shear forces at the knee.[4,33]

The talus-ankle mortis articulation causes the lower extremity to externally rotate with subtalar joint supination.[4] On the other hand, open kinetic chain exercises, such as knee flexion and extension, allow much of the torque generated by the quadriceps to be absorbed by the patellofemoral joint. Where as closed kinetic chain exercises decrease the patellofemoral joint forces.[4,34]

In closed kinetic chain exercise, torque is generated by muscle action through a series of combined neurological synchronized movements that allow for acceleration and deceleration of the lower extremity.[4]

Bunton[15] states that acceleration and deceleration of the lower extremity during locomotion occurs in three different planes. Weight, joint hypermobilities and hypomobilities, terrain, and ground reaction forces are all factors that affect these factors. Therefore, muscle actions can be affected significantly and result in abnormal compensations during closed kinetic chain activity.[15]

CHAPTER 7

Proprioception

Developing proprioception and incorporating intricate timing with muscular force are essential for accurately performed functional activities. Proprioception is defined as "the awareness of posture, movement, and changes in equilibrium and the knowledge of position, weight, and resistance of objects in relation to the body"[35] and is essential to the athlete.[15] Movement or change in the position of a joint stimulates the receptors that allow the conscious appreciation of the position of the limbs in space. Specialized mechanoreceptors within the joint capsule have been assigned a prominent role in signalling joint position.[36] The proprioceptors are located in muscle (muscle spindles), tendons (Golgi tendon organs), and in and around synovial joints (joint kinesthetic receptors).[15]

When a joint is injured, followed by rest and/or immobilization, the joints, muscles, and proprioceptors "forget" their role in controlling lower extremity deceleration and acceleration forces, which results in decreased function regardless of muscle girth.[4] Thus developing proprioception and incorporating muscle force and timing are essential for performing functional activities accurately and safely.[4] The athlete/patient may complain of the knee or ankle "giving out" if proprioception is not regained.[4] Weight bearing activities are needed to re-educate the proprioceptive process of the injured sensory endings.[4] Closed kinetic chain exercises facilitates normal proprioceptive feedback by the functional use of multiplanar movements.[4]

Buntons[4] research suggests that overlooking the lack of "position sense" in the injured athlete/patients rehabilitation process may be most responsible for recurring injuries even after muscle and ligament integrity has been restored.[37] Closed kinetic chain exercise uses the bodys natural movements and planes, thus all proprioceptors are stimulated to some capacity.[4] Open kinetic chain exercise operates in one plane (isolated exercise) and limits the development of full joint proprioception by not stimulating all of the proprioceptors necessary for functional movement.

Ruffini's endings are located in the fibrous layer of the joint capsule. They have their greatest distribution in the capsular regions of most stress in the proximal joints.[13] Ruffini's endings monitor the direction and rate of joint position changes.[4] Ruffini's endings are considered strong postural receptors as they are primarily in the proximal joints and have a very low threshold. They are active in every position of the joint emitting a resting discharge.[13] Ruffini's endings are slowly adapting and are sensitive to changes in the pressure of intracapsular fluid.[13] Ruffini's endings can be characterized as dynamic and static mechanoreceptors and respond to isometric changes in muscle tone.[13] A closed chain position may be necessary to sufficiently stimulate the Ruffini's endings as they are more numerous on those aspects of the joint capsule that undergo the greatest changes in stress during natural joint movement.[13]

Pacinian corpuscles are also located in the fibrous layer of the joint capsule.[13] They are the largest, most highly structured end organs located in cutaneous and tendinous tissue.[4] Their greatest distribution is in the distal joints, and they have a faster conduction velocity than the Ruffini's endings.[13] Pacinian corpuscles respond to high velocity changes in joint position, acceleration and deceleration. They are low threshold, but unlike the other proprioceptors, they are rapidly adapting therefore they are active for a brief period, at the onset of joint movement, and when and where sudden changes of stress occur.[13] Closed kinetic chain activities provide rapid joint movements at a variety of velocities and joint stresses, thus enhancing the development of pacinian corpuscles.[4]

Golgi-mazzoni corpuscles are joint receptors present along the inner surface of the joint capsule.[13] They respond to perpendicular axial loading, but not to stretching of the capsule.[7] Gray[13] states that this is a strong indicator of the need for perpendicular axial loading facilitated by closed chain weight bearing.

The golgi ligament endings are joint receptors that are found in both the intrinsic and extrinsic ligaments are the golgi ligament endings. They monitor the position of the bony segments that contribute to a joint.[13] The golgi ligament endings are the largest receptors found in intrinsic and extrinsic ligaments. They have a full spectrum mechanical threshold, and are slowly adapting to tension or stretch on ligaments.[13] Because golgi ligament endings respond to tension stimuli, Gray[13] states that there is a strong need to emphasize the need for accurate biomechanical and physiological stress to the joint during rehabilitation.[4]

The Golgi tendon organ consists of a mass of nerve endings inclosed in connective tissue and embedded in the tendon.[4] GTO's are located in the tendon near the musculotendinous junction.[13] The GTO's respond to both contraction and stretching of the muscle.[13]

Stretching of the GTO signals the CNS and causes the muscle to relax.[4] Stimulation of the GTO causes inhibition of muscle and its synergist and facilitation of the antagonists in the ipsilateral side and opposite reflex action on the contralateral side.[13] Gray[13] states that Golgi tendon organs are most effectively stimulated by combining a stretch and contraction at the same time.

The muscle spindles are located within the muscle fibers, with the greatest concentration in the middle of the muscle belly.[13] The muscle spindles are slow adapting monitoring both the change in length and the rate of change in length.[13] When the muscle spindle is stretched, the impulse is sent from the sensory nerve at the center of the muscle spindle to the central nervous system.[4] The muscle spindles are innervated by motor nerves as well as sensory nerves.[13] The sensory (afferent) fibers 1A and 1B neurons provide information about the rate and amount of change in muscle length. Motor (efferent fibers) neurons contribute to the production of smooth, controlled and coordinated movement (gamma motoneurons).[13] Gray[13] states that the production of either joint motion or joint stability requires that muscles function as groups rather than individually, therefore the muscle spindle, because of its efferent and afferent portions, provides muscles with the capability for maintaining adequate joint stability, especially during chain reaction locomotion.

Proprioception is very important in rehabilitation after injury. Failure of ACL reconstruction has been attributed to loss of proprioception.[36] Arnoczky when reviewing the anatomy of the ACL, mentions the existence of nerve fibers within the ligament, fibers which he states may serve a proprioceptive function.[36] Abott also mentions this stating that the ligaments of the knee have a rich sensory innervation that allows them to act as the first link in the "kinetic chain".[36] Barrack[36] concluded that patients who sustain a complete ACL tear may experience a decline in proprioceptive function, which may contribute to the progressive instability and disability that commonly occur over time.

CHAPTER 8

Rehabilitation

Knowlege of the dynamic function of the lower extremity requires an understanding of the biomechanics of the foot and ankle to understand how the kinetic chain works. Gray[13] defines biomechanics as a science that helps us understand the totality of the human organism and the relationships and interactions that the various body parts, segments and systems have with each other that contribute to the ability or inability to function. He defines applied biomechanics as an art that allows us to utilize intuitive faculties to translate our understanding of locomotor biomechanics into a practical and functional model of function or dysfunction.

Functional rehabilitation as stated by Markey[38], is an embellishment of the traditional concepts of rehabilitation which are motion and strength. Functional rehabilitation incorporates the concepts of agility, proprioception, and gives confidence of the individual when performing whatever task he or she wishes to undertake.[38] Open kinetic chain exercise allows quantitative clinical assessment of muscle strength.[15] However a strong relationship between open kinetic chain exercise and functional activity has not been established.[38]

In recent years, surgical reconstruction procedures, and consequently, rehabilitation protocols have undergone considerable change. A better understanding of graft fixation and revascularization as well as less invasive, less traumatic surgical techniques, has allowed a more aggressive approach to the recovery of range of motion and quadriceps strength during the very immediate post-operative phases of rehabilitation. Thus, as earlier return to functional activities is possible.[39]

DeCarlos[41] compared traditional and accelerated rehabilitation programs following ACL reconstruction. They discovered that in the group of subjects receiving the traditional rehabilitation program that there was a number of patients experiencing classic extensor mechanism dysfunction. They changed their protocol to include closed kinetic chain strengthening exclusively. It was suggested by several authors that closed kinetic chain rehabilitation might allow for better patellar tracking with minimal stress to the ACL graft by maintaining good joint congruency.[26,34,40,41]

Through closed kinetic chain quadriceps strengthening and decreased dependance on the straight leg brace, the patients demonstrated earlier return of quadriceps tone.[40] With the accelerated rehabilitation program bilateral knee bends and calf raises were done progressing to unilateral exercise as tolerated. The patients started stairmaster workout as early as one week post-op.[40] Isokinetics were only used every 4-6 weeks for evaluation of their strength only.[40] Accelerated ACL rehabilitation programs advocate early incorporation of closed kinetic chain exercises and early return to preinjury level.[39]

Ohkoshi[32] studied the biomechanical analysis of rehabilitation in the standing position. He found that in a standing position with the knee flexed, the mean shear force exerted on the tibia was a posterior drawer force at each of the knee flexion angles tested. He concluded that the quadriceps femoris muscles and hamstrings are simultaneously contracted in the standing position with the knee flexed. This simultaneous contraction of the quadriceps and hamstrings seems to be a significant factor of these results. If considering the present postures used in exercises during rehabilitation after reconstructive surgery of the ACL ligament, it is quite useful to know that the posterior drawer force is increased by a very simple motion of anterior flexion of the trunk.[32]

The results from Okoshi's[32] study suggest the possibility that exercise in the standing position with knees flexed and the trunk anteriorly flexed can be performed in the early stages of rehabilitation after reconstruction of the ACL. Weight bearing has conventionally been prescribed in the early stages after surgery. Ohkoshi[32] believes that cocontraction of the quadriceps and hamstrings should be done in weight bearing. This method has the advantage of being an easy exercise for patients and favorable effects are expected in various aspects including muscle strength, particularly endurance, proprioceptive function of affected lower limbs, and prevention of bone atrophy.[32]

A two dimensional model analysis was performed by EMG to show the shear force exerted to the tibia in the standing position with both knees flexed at various angles. The effects of change of trunk posture were also analyzed. Results showed that in most positions with the knee flexed at 30 degrees or more and the trunk anteriorly flexed at 30 degrees or more and negative shear force (posterior drawer), was estimated to occur in more than 90% of the population.[32] The second conclusion of the study was that in the standing position, simultaneous contraction of the quadriceps and hamstrings was observed in all subjects and the muscle activity of the hamstrings was enhanced by anterior flexion of the trunk. The third conclusion was that the mean values of the shear force exerted on the tibia in the standing position were negative in each subject, revealing posterior drawer forces, at 30 and 60 degrees in particular the posterior drawer force was significantly increased by anterior flexion of the trunk.

To use this posture as a muscle exercise in the early stages after ACL reconstruction the safety range was estimated statistically. Shear forces were estimated as negative in 90% of the population in most of the positions with the knee flexed at 30 degrees or more and the trunk anteriorly flexed at 30 degrees or more. This angle of flexion for the knee and trunk should be applied to exercise.[32]

A study by Tegner[42] compared isokinetic versus functional training without specific strength training in rehabilitation of ACL and PCL injuries. The isokinetic training group started with training on high speed (180-300 degrees/sec) and the speed was gradually reduced as strength increased. The functional training was aimed at restoring confidence in the knee by enhancing the dynamic stability. They used a six step scheme. During the first step the patients mainly trained in order to be able to walk and jump on two legs without problems. The exercises were gradually made more difficult. When the patients complete the training they should be able to run, hop, and cut without difficulty. He found that less people completed the isokinetic training due to low compliance to this type of exercise (30% of their patients stopped training before they normalized their strength).[42] The short term results showed that strength, performance test, activity level and functional score were about the same for both groups.[42] Tegner[42] concluded that functional training without any specific strength training was a good alternative to pure strength training. The importance of coordination exercises and functional training have also been pointed out by Ihara and Nakayama.[43]

A vital component of the functional rehabilitation program is the causitive activity itself. In otherwords, the cause becomes part of the cure.[35] This is the ultimate goal for the therapist.

Gray[32] states that most of what the lower extremities does is done at a subconscious level, constantly reacting and interacting with the environment in order to walk, run, and jump. Gray[32] describes the function of the lower extremities as a "chain reaction". A chain reaction is a reaction of the entire kinetic chain in order to accomplish the functional goals of the patient. Basic to the function of the lower extremity, in all forms of activity, is the regaining of stability in order to demonstrate mobility.[3]

When designing the patient's rehabilitation program, the therapist must understand the biomechanics, motor function, and how the involved tissues are integrated into the lower extremity kinetic chain system. Gray[32] states that the functional kinetic chain rehabilitative strategy is to design the environment to facilitate the appropriate chain reaction. And at the same time having clinical control over which joint or joints dominate the action and in which plane or planes the action predminatly takes place.[3] Since it is the goal of closed kinetic chain exercise to return the traumatized tissue back to the activity that caused the injury, it is imperative that the rehabilitative program provides calibrated and progressive stress, functionally controlled motions, and reactive responses.[3]

The rehabilitative goals should be based on an understanding of the neuromuscular system, and the program must stress the proprioceptors.[3] In a closed kinetic chain system, motion, stability, flexibility, and strength are facilitated simultaneously, not independently.[3] Gray[32] states that closed kinetic chain exercises begin with function and end with function. He also says that functional testing determines function, not artificial testing within nonfunctional environments.[3]

CHAPTER 9

Proprioceptive Aspects of Rehabilitation

Position sense, or proprioception, is often over-looked in rehabilitation programs. Proprioception, which is an integral part of closed kinetic chain activities, simultaneously promotes variations in concentric, eccentric, and isometric muscle contractions during the activity.[33] This muscular coordination allows the body to control joint motion. Proprioceptive exercises enhance the bodies ability to adapt to changing stresses encountered in athletic or functional activities.

Along with a good understanding of proprioception and the importance it plays in rehabilitation, an understanding of the functional dynamics of the lower extremity is also important. It is important to understand how to combine the two to achieve the best possible outcome for the patient. A functional understanding of the dynamic motion of the foot and leg, requires a working knowledge of the biomechanics of the foot and leg. This knowledge is based on an appreciation of the motion, the axis of motion, and the acceleration, deceleration, and stabilization of these motions as they occur in the lower extremity.[4]

The BAPS (Biomechanical Ankle Platform System) board is a commonly used closed kinetic chain device used for proprioception training of the lower extremity. The biomechanical design of the BAPS board directly correlates with closed kinetic chain function. The BAPS board promotes biomechanical function from the ground up, as well as facilitating changes in joint position by allowing multiplanar movements.[4,13] The BAPS board encourages the patient to control pronation at the knee and subtalar joint.[4] Since the proprioceptors are dysfunctional following injury and/or immobilization, the BAPS board may be awkward for the patients at first.[4] The goal of the BAPS board is to stimulate proprioceptors in the primary and secondary restraint structures of the joint that have been damaged secondary to an injury. Because of the BAPS boards biomechanical design, it is a simple and effective way to clinically control and progressively rehabilitate the lower extremity.[13]

The BAPS board, being a closed chain activity, promotes neuromuscular coordination of all lower extremity muscles.31 The muscles acting on the ankle and knee contract concentrically and eccentrically to initiate and control motion, while the muscles of the hip and trunk isometrically stabilize the body over the foot.[33]

To enhance the pacinian corpuscles, closed kinetic chain rehabilitation can be used to provide the combination of rapid joint movements at a variety of velocities and joint stresses.[4] A specific example would be plyometrics which can allow for such changes in acceleration an deceleration.[4] The leg press is a good piece of equipment to perform plyometric activities as it allows for acceleration, deceleration, and incorporates multiplanar movements by changing the patients foot plant.[4]

The Golgi-Mazzoni corpuscles respond to perpendicular axial loading, but not to stretching of the capsule. Weight bearing activities provide a perpendicular axial load to the joint.[4] The Nordic Striders and slide boards are good examples of sport-specific activities that provide ground reaction forces.

The Golgi Tendon Organ detects muscle tension and responds to the contraction and stretching of a muscle. Some specific exercises would be hip movements with theraband, leg press exercises, plyometrics, and mini squats.[4]

Techniques that can be used to stimulate the muscle spindles include standing, stationary cycling, mini-trampoline exercises, medicine ball workouts, walking, running, and the body blade which incorporates oscillatory sensations.[4]

CHAPTER 10

Clinical Aspects of Rehabilitation

Strain to the ACL is reduced by co-contraction of the hamstrings and quadriceps. Co-contraction can be achieved through weight-bearing exercises, such as the squat.[5] When rising from a squat, simultaneous hip and knee extension occurs. The rectus femoris and the hamstrings are both active during this motion. As the hip extends, the rectus femoris lengthens while the hamstrings shorten, but as the knee extends, the rectus femoris shortens as the hamstrings lengthen. This cannot be reproduced with isolation exercises.[5]

The squat allows isometric, eccentric, and concentric muscle contractions to occur in one exercise and places less strain on the ACL than open kinetic chain exercise.[44] The squat has been said to be a dangerous exercise because of the potentially damaging effects on the back, hips, knees, and ankles.[45] The squat happens to be one of the most frequently performed daily activities. You squat when you sit down and stand up from a chair, when you get into and out of the car, and when you walk up and down the stairs.[45]

When performed correctly the squat is an excellent closed kinetic chain exercise. There are many different variations of the squat that are also very good closed kinetic chain rehabilitation exercises. Some of these exercises include step-ups, lunges, wall squats, half squats, quarter squats, backward (retro) step-ups, and side lunges.[45] The squat can be used to help develop functional strength, power, agility, balance, and coordination.[45] Day[45] states that "in my opinion, squatting exercise is the best way to functionally train the legs".

Henning[26] found that the one leg half squat produced only 21% elongation of the ACL when compared to a 80 pound Lachmans test. He also stated that the knee should not be straighter than 20 degrees nor flexed more than 90 degrees when performing the squat. Henning[26] stated that the leg press could be substituted for the squat, as it is biomechanically equivalent .

O'Neil[44] developed a variation of the squat using a squat board. With the squat board patients can perform a variety of exercises against the resistance of rubber tubing.

Gray[13] states that therapists should follow two basic principles when rehabilitating their patients. The first is that therapists should not hesitate to use their skills first and machines second. Gray[13] says that the equipment is not important, it is the therapist that is the most important part of the environment. The second principle is to choose therapies in which the patient has control of their motions.[13] Panariello states that you have to "remember that the body controls the weight, the weight doesn't control the body."[5] Gray[13] also believes that "motion and stability, flexibility, and strength are facilitated concurrently, not independently. Progression within exercise environments is based on performance and symptoms, not an artificial time line".[13]

An article by Galik[5] reviews specific rehabilitation procedures that Hobler uses for post surgical ACL patients, other knee problems, and soft tissue hamstring damage. In the early stages of rehabilitation, Hobler begins with toe raises, simulated walking while sitting in a chair, and bilateral knee bends. To these exercises he adds standing quadriceps sets, isometric leg raises, the leg press, and rockerboard exercises.[5] For the more advanced patient, resistive cords are used. At one month post-op aerobic activity is started. Hobler found that good initial aerobic exercise machines are the stair climber, the rowing machine, and the stationary bicycle. Plyometrics are mixed in with medicine ball and slide board activities. Hobler suggests that the therapist should use a variety of equipment and exercises to maintain a higher level of motivation in the patient. The program should be designed to target the patients functional needs.[5] One advantage to most of these close kinetic chain exercises, is that if the patient is motivated they can do most of these exercises on their own. Panariello states that the only equipment he uses in rehabilitation is barbells and dumbbells.[5] Panariello also states that most machines are structured for the average person. But machines don't demand balance, coordination, and proprioception.[5] The closed kinetic chain exercises that Panariello recommends for strength and power development are the deadlift, muscle snatch, back squat, clean shrugs, push press, lunges, power cleans, split jerk, clean pulls, snatch, standing toe raises, and slow clean pulls.[5]

Although closed kinetic chain activities seem to be the safer more functional route to go in rehabilitating the lower extremity, Panariello notes two exceptions for using open kinetic chain exercises.[5] The first exception he makes for using open kinetic chain exercises, is for body builders who need to isolate a muscle or group of muscles for hypertrophy. The second exception is for patients who have suffered an injury to the lower extremity that requires them to reduce forces on the feet.[5] In these situations, he recommends using open kinetic chain exercises to maintain the strength in the uninjured isolated muscles.[5]

One other positive thing that closed kinetic chain exercises have to offer, is that the equipment used is relatively inexpensive and most facilities already have the equipment. Equipment ranges from exercise with just the patients body weight, to free weights, stair climbers, treadmills, slide boards, BAPS board, and sport cords.[5]

The stair climber provides a variety of work-outs including aerobic, anaerobic, and interval training. The stair climber serves as a closed kinetic chain workout for the legs and back. Galik[5] found that stair climbing gait offers biomechanically correct movement, along with the abilty to customize the programs to the patients needs.

The slide board enhances lateral thigh strength as well as improveing proprioception of the lower extremity.[15] The hamstrings play a significant role in providing knee joint stability and are therefore, of great importance in ACL rehabilitation.[6] Grahman[6] found that the slide board produced the highest percent maximum voluntary contraction of the hamstrings.

Treadmills are also a good closed kinetic chain rehabilitation tool. Rehabilitation and conditioning programs can utilize the options of walking, running, lateral walking, and retro walking on the treadmill.[5]
The BAPS board is an excellent proprioceptive device that can be used for the functional rehabilitation of ankle sprains, ACL deficient or reconstructed knees, hip, lower extremity, and low back injuries.[5]

One of the more inexpensive devices used for closed kinetic chain rehabilitation are the sport cords made from surgical tubing. They are easy to use, light weight, and available in a variety of resistances.[5]

Many of the proprioceptive devices can be made relatively inexpensively using plywood and various sizes and shapes of balls for multidirectional movements.[46] Dowels can be used with plywood for unidirectional balance activities. Sport specific activity can be initiated while balancing on the proprioceptive board.[46] These proprioceptive boards can be used in a variety of functional ways. The difficulty can be increased or decreased by performing exercises with eyes open versus closed and one foot versus two. Blair[15] uses the small uni-directional board for proprioceptive toe raises, which involves slowly tilting the boards to provide a constantly changing surface to stimulate uneven sporting terrains and environments. To enhance intrinsic pathways, the patient can utilize sport specific drills, for example dribbling or passing a basketball while balancing on a proprioceptive board.[15]

Another proprioceptive device you can utilize in the clinic is the pogo ball, which is relatively inexpensive to buy. You can start the exercise progression by standing on the pogo ball in between two chairs while holding onto the chair backs. Blair[15] suggests that the patient "write" the alphabet with their feet while balancing on the ball, then progressing to hopping patterns.

One of the more common pieces of closed kinetic chain equipment is the stationary bicyle. Most facilities have at least one stationary bike. Patients can be progressed from sitting biking, standing biking, and retro biking.

Standing stationary biking is a more challenging exercise then sitting biking and allows for integrated group muscle action. Retro biking is even more challenging and difficult for the patients. Stationary biking produced only 7% as much elongation as an 80 pound Lachman test, suggesting that quadriceps rehabilitation can be done more safely using the stationary bicycle.[26]

When selecting an exercise program for an individual with an ACL injury, the primary considerations are 1) safety (primarily minimizing anterior/posterior shear forces), and 2) the effectiveness of the exercise in strengthening the appropriate muscles.[6] These two points seem to be of utmost importance in rehabilitation in order to achieve optimal results for the patients. Closed kinetic chain exercises appear to be an appropriate and effective means of improving quadriceps and hamstring strength while following the above considerations at the same time.

CHAPTER 11

Conclusions

When comparing closed and open kinetic chain exercises, the primary difference is the relationship of the lower extremity end segment to the ground and gravity. In the open kinetic chain exercise, the end segment is free and in the closed kinetic chain exercise the end segment is fixed.[13] In closed kinetic chain exercise, motion occurs both distal and proximal to the axis of motion, while open kinetic chain exercise produces motion only distal to the axis of motion at the joint.[13]

Gray[13] describes muscle function in closed kinetic chain exercise as decelerating, transforming, stabilizing, and accelerating motion. Muscle contraction in closed kinetic chain exercise includes eccentric, concentric, and isometric contractions. Open kinetic chain exercise only utilizes concentric muscle contractions.

Closed kinetic chain exercises facilitate the dominant motions at various joints using an integrated system. Open kinetic chain exercises for the lower extremity are based on isolation of movement.

Gray[13] concluded that closed kinetic chain function creates biomechanically consistent stress and strain within the soft tissues because of the appropriate reactive and loading mechanisms. In comparison, open kinetic chain rehabilitation of the lower extremity creates biomechanically inconsistent stress and strain within the soft tissues.[13]

Stabilization with closed kinetic chain function is produced intrinsically through normal postural mechanisms. In contrast, open kinetic chain joints provide stabilization of the various exercises through the use of artificial means extrinsically.[13] Most open kinetic chain exercises require that the patient act upon the environment as opposed to reacting to the environment as the closed kinetic chain does.[13]

Gray[13] states that open kinetic chain exercises of the lower extremity facilitates probable foreign and erroneous proprioceptive feedback, and occurs in only one cardinal plane. The closed kinetic chain exercises accurately facilitate normal proprioceptive feedback mechanisms and strongly enforces and has a high degree of carry over into functional activity.[13]

One of the biggest advantages closed kinetic chain exercise has over the open kinetic chain exercise is that the techniques available for closed kinetic chain rehabilitation are virtually unlimited. In contrast, open kinetic chain exercise is limited by the equipment that is available.

The ultimate goal of closed kinetic chain exercise is to enhance proprioception, thus gaining lower extremity stability when an unpredictable change in direction or speed occurs.[4] Bunton[4] states that performing open kinetic chain rehabilitation does not expose the lower extremity to proprioceptive feedback mechanisms.

Closed kinetic chain rehabilitation is shown to decrease shear forces, increase proprioception, and increase muscle group coordination through examples of progressive exercises.[15] Bunton[4] concludes "that closed kinetic chain rehabilitation is an economical, efficient, and effective means of rehabilitation, with the ultimate goal of enhancing proprioception, thus gaining lower extremity joint stability.[15] Bunton[4] also states that documented research comparing closed and open kinetic chain rehabilitation is clinically significant. He states that the lower extremity is not just controlled by the quadriceps and hamstring muscles, but by a complex movement system comprised of deceleration, acceleration, pronation, and supination of the muscles and joints of the lower extremity.[4]

Closed kinetic chain exercises allow for reactivation of the proprioceptors, whose role is to sense the amount, speed, and timing of joint positioning.[4] Closed kinetic chain exercises function in multiplanar environments, use acceleration and deceleration, and can incorporate countless external stimuli, allowing for a much more sport-specific form of rehabilitation.[4]

Isolated exercises, or isokinetic exercises, still appear to be standard protocol even though there is overwhelming evidence that such isolation of knee movement increases tibial translation, compromises secondary restraint structures, increases shear forces at the knee, and stretches ACL grafts when involved.[4,34]

Seto[17] recommends implementing closed kinetic chain exercises early in the rehabilitation process. Shelborne[34] and Nitz[34] found that the increased weight bearing found with closed kinetic chain exercises provides inherent joint stability, thus allowing for more strenuous pain-free workouts without the increased shear forces at the patellofemoral joint that can accompany open kinetic chain exercise.

John-Yack[10] concluded that open kinetic chain knee extension exercise placed repeated stress on the already injured tissue and on tissues that do not primarily control anterior tibial displacement. He also concluded that the limits of anterior tibial displacement establised during the Lachman test were not approached during the parallel squat exercise. There was also significantly less anterior tibial displacement during the parallel squat exercise compared to the knee extension exercise from 66 to 10 degrees of knee extension. In the normal knee, the primary passive structure for limiting anterior tibial displacement between 0 to 60 degrees of motion is the ACL. The effectiveness of closed kinetic chain exercises in limiting anterior tibial displacement appears to be a result of the complex interactions of ligamentous and soft tissue restraints, condylar geometry, active muscular control, and tibiofemoral contact forces at the joint interface generated during weightbearing activities.[10,47]

Closed kinetic chain exercise is an economical, efficient and effective means of rehabilitation that is limited only by the therapists imagination. Performing multiplanar closed kinetic chain rehabilitation allows for sport-specific adaptations to occur, so the athlete can have a safer return to activity with decreased reinjury rates.

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